Assessment of the Fire Suppression Properties of Mists of Aqueous Potassium Acetate

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ABSTRACT

The use of water-based fire suppression systems in cold regions requires methods or additives to prevent the water from freezing. To this end, we examined the impact on the fire suppression properties of three typically used additives for freeze protection: ethylene glycol, propylene glycol, and potassium acetate. Thermodynamic analysis shows that although the addition of the glycols (30% to 65% by volume) can provide freeze protection down to -12^{o}C, the glycol additives are predicted to increase the minimum suppressant concentration needed to extinguish a flame relative to pure water. Similar analysis for potassium acetate shows that it can also provide freeze protection with the added benefit of potentially increasing the fire suppression capability of water. In order to assess the impact of the addition of potassium acetate on the fire suppression effectiveness of water mist, we measured the concentration of mists made from 6.25% potassium acetate by weight in water (freezing point -8^{o}C) required to extinguish a propane flame in a cup burner apparatus. The potassium acetate mist in the form of sub-10 micrometer diameter drops was > twice as effective based on weight of mist added to the air stream compared to mists of pure water of the same drop size. Incremental mass-based mist suppression effectiveness with potassium acetate solution concentration decreased with increasing additive concentration.

INTRODUCTION

This paper is an experimental follow-up to an NRL modeling study examining the freezing point protection options for water mist-based fire suppression systems for the U.S. Navy's Ship to Shore Connector (SSC), a high speed transportation vehicles for sea-based operations [1]. The SSC requires a fire-fighting system that is halon-free with a minimum thermal tolerance requirement of -12.2^{o}C (10^{o}F). The preliminary thermodynamic analysis focused on two commonly used categories of solutes to depress the freezing point of water: glycols and metal salts. Propylene glycol solutions (commercial product "Fire fighter PG") are available for water sprinkler systems. These systems deliver large drops (400-1000 μm), use large quantities of water, and may not be suitable on small vehicles such as SSCs. Water mist systems in contrast deliver small drops (less than 200 μm), which can evaporate rapidly and cause significant gas phase cooling. Complete evaporation of the small drops in and near the fire forms a mixture of water and glycol vapor. Analysis shows that the glycol vapor releases heat upon combustion and thus negates the gas phase cooling effects of the water. On a mass basis, glycol solutions are predicted to be less effective than pure water [1].

On the other hand, alkali metal salts can provide the needed freeze protection and also greater fire suppression effectiveness over mists of pure water due to the chemical suppression capability of the additive metal ions [1]. Ref. [1] estimated that less salt solution (as much as 40 % less by mass) in the form of a fine mist are likely needed compared to pure water to suppress

SSC fire scenarios. This paper experimentally examines the fire suppression effectiveness of solutions of potassium acetate, a commonly used additive for freeze point protection.

EXPERIMENTAL

Experimental Hardware

We performed flame extinction experiments with the cup burner experimental setup as generally described by Fisher et al. [2]. The setup was modified according to the schematic shown in Fig.1. The most significant modification was a Secondary Air Flow which allowed better control of the mist density. Mists of sub 10-μm diameter drops, generated using piezoelectric-based ultrasonic mist generators, were entrained by a Primary Air Flow in the Entrainment Tube. A range of mist densities could be achieved using either a single-head mister (M-0111 Mist Maker, Heri) or a three-head mister (DK3-24 Mist Maker from Ocean Mist). The mass of water drops entrained depended on the Primary Air Flow. The Secondary Air Flow mixed with the primary mist-laden air downstream of the mist entrainment region but upstream of the flow conditioning tubing. This flow arrangement allowed the concentration of mist drops and nitrogen in the total air flow to be controlled independently while keeping the total air flow constant through the cup burner. Both the Primary and Secondary Air Flows were controlled using a flow meter (Sierra Model 840L) and a needle valve and passed through separate water bubblers to humidify the air/nitrogen flows before entering apparatus.

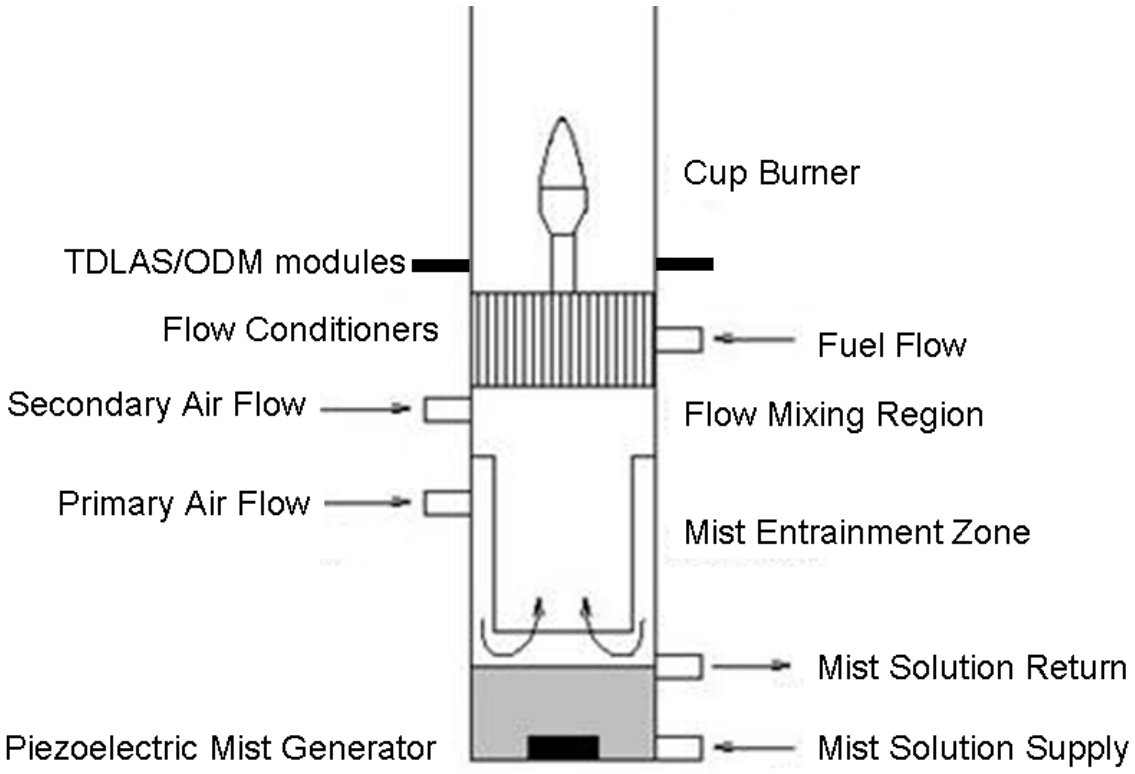

Figure 1. Schematic of the mist-adapted cup burner apparatus.

The cup burner cup was enclosed in a rectangular glass chimney, downstream of the flow conditioning used to make the oxidizer and mist flow uniform. A contraction at the exit of the chimney reduced back-draft influences. We studied propane flames; the propane flow through the cup was controlled using a flow meter (Sierra Model 840L) and a needle valve. The cup was filled with 1-mm diameter glass beads to make the fuel flow velocity profile uniform across the cup.

The concentration of nitrogen in the co-flow around the cup was varied by controlling the flow rates of nitrogen and air in the Secondary Air Flow. A Sierra flow controller and flow meter with a needle valve permitted control of the nitrogen concentration while maintaining a constant total flow.

The height of the liquid solution surface above the mister, the temperature of the fire suppression solution, and the voltage supplied to the ultrasonic mist generator determined the amount of mist produced by the ultrasonic mist generator. A mist solution reservoir, pump, and a return tube from the mister in the cup burner base to the solution reservoir maintained a constant solution liquid height above the mist generator. We ran the mist generator and circulation pump before each extinction experiments in order for the solution temperature in the reservoir to reach steady state.

The piezoelectric ultrasonic mist generators operate by producing a high frequency oscillation from a piezoelectric disk. The oscillation can generate waves in a liquid above the disk. For a narrow range of liquid heights above the disk, small drops are ejected from the surface of the liquid, forming the mist. The frequency range of the oscillations is typically between one and two MHz. The one-head and the three-head ultrasonic mist generators used in this study both required an input voltage of 24 VAC. In order to control the mist output, we varied the voltage supplied to the ultrasonic mist generator by adding high precision, high power resistors in series with the ultrasonic mist generator. Using resistors to control the voltage ensured that the frequency of the supplied alternating current was not changed. Increasing the circuit resistance decreased the voltage across the mist generator and decreased the amount of mist generated. The useful range of added resistance for adjusting the mist output was between zero and 15 ohms for the single piezoelectric head. The equivalent resistance range for the three-head mist generator was calculated to be zero to five ohms. The power drawn by each piezoelectric head was experimentally determined to be ~ 10 watts. We used 1 ohm and 5 ohm, 15 watt power resistors to control the single head mist generator's output and 0.1 and 1 ohm, 100 watt power resistors to control the output from the three-head mist generator. Resistors were added in series to the circuit using toggle switches. This power supply configuration permitted fast and precise changes in resistance that resulted in very good control of the output of the ultrasonic mist generators.

Mist concentration in the air flow as well as water vapor in the air stream were determined using tunable diode laser absorption spectroscopy (TDLAS) [3]. The amount of transmitted light obtained during the TDLAS measurement provided optical density data used to quantify the mass of water as liquid drops in the oxidizer stream using Beer's Law [3].

Experimental Procedure

Extinction experiments were conducted following a strict protocol. The cup burner was first ignited with no added nitrogen or mist in the oxidizer flow. Then the mist generator was turned on and the system was allowed to reach steady state. The system was considered to be at steady state when the temperature of the solution in the reservoir no longer changed with time and the cup burner flame was stable and attached. The nitrogen concentration was then gradually increased while keeping the overall oxidizer flow rate and mist concentration constant. The mist concentration was kept constant as determined by the TDLAS ODM measurement by manually adjusting the mister supply circuit resistance. After adjustments in the nitrogen or mist concentration, the system was allowed time to respond to the changes, typically about a minute. Extinction concentrations measurements were made immediately after the flame was extinguished.

Results

Extinction data are presented in Fig. 2 for mists of pure water (sub-10 μm diameter) and for mists made with solutions of 3.2% or 6.25% potassium acetate in water (by mass) to extinguish a propane flame (0.21 lpm) in the NRL mist adapted cup burner apparatus. Symbols indicate the extinction concentrations of nitrogen and mist in combination. An experimentally derived scattering extinction coefficient of 0.48 liter/g-cm was used to convert the ODM data to concentrations. In the plot, regions above each of the lines indicate those concentrations in the co-flow surrounding the cup that would extinguish the flame; flames can exist for those concentration combinations below each of the lines. A diamond symbol indicates data for mists of pure water. A linear correlation of the data for mists of pure water in combination with a known physical agent, nitrogen, suggests that the mist suppression behavior is consistent with a physical gaseous agent acting thermally to suppress the flame. This behavior is typically assumed for the suppression mechanism of water mist; this assumption is validated here for the first time. Extrapolation of the linear fit to a water mist only (no nitrogen) extinction concentration gives a pure water mist extinction of 0.17 g/liter-air (12.2% water in air by mass) in very good agreement with the value determined by Fisher et al. [2].

As seen in Fig. 2, the stable flame region is dramatically reduced for mists of either a 3.2% or 6.25% aqueous potassium acetate solution; the 3.2% mist is ~2.3 times as effective at flame extinction as the pure water mist and the 6.25% mist is ~ 2.8 times more effective. Doubling of the additive concentration in the mist from 3.2% to 6.25% results in a 25% increase in the suppression effectiveness. The mist with additive data in Fig. 2 also does not follow a linear correlation. A third order polynomial has been used to fit the mist with additive data. The non-linear extinction behavior with increasing agent concentration as well as the decrease in incremental suppression effectiveness with increasing agent concentration have been studied for alkali salts [4]. The observations are indicative of two limiting suppression phenomena: a thermodynamic limitation of the concentration of the catalytic species in the flame environment responsible for suppression and a limitation of any catalytic suppression agent to only lower the key flame propagation radicals to their equilibrium values. An additional requirement for flame extinction is needed, that of lowering the flame temperature. Water in the form of small drops very effectively meets this requirement. Under our experimental conditions, potassium acetate

added to the water mist to provide freeze point protection down to ~ - 8°C significantly enhances the fire suppression effectiveness of the mist.

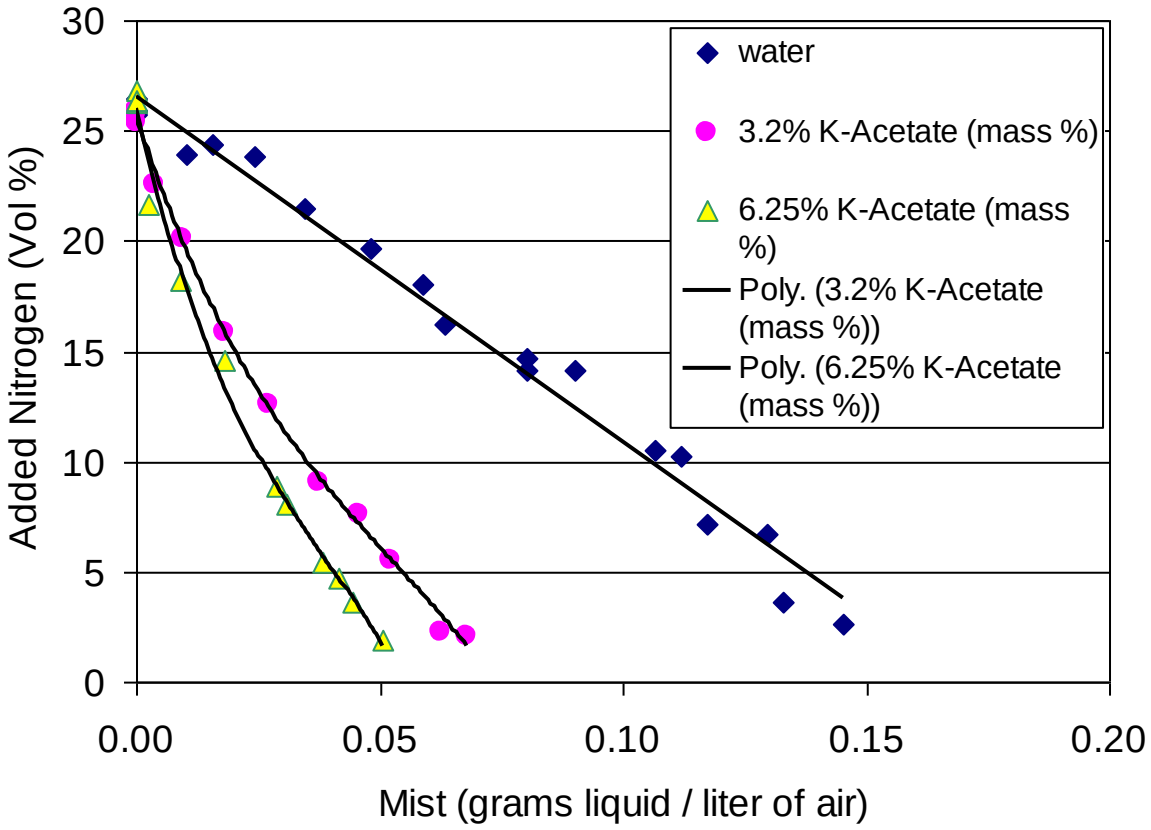

Figure 2. Concentrations required to extinguish a propane flame in a mist-adapted cup burner apparatus with nitrogen and pure water mist (diamonds), nitrogen and mist of 3.2% aqueous potassium acetate (circles), and nitrogen and mist of 6.25% aqueous potassium acetate (circles).

Conclusions

We investigated the fire suppression effectiveness of mists of aqueous potassium acetate solutions against propane flames in a mist adapted cup burner apparatus. Mists of sub 10 μm diameter drops of 6.25% potassium acetate by weight in water were more than twice as effective at extinguishing the flames compared to mists of pure water. Mist suppression effectiveness increased with increasing additive concentrations; the incremental suppression effectiveness decreased with increasing additive concentration. The increased suppression effectiveness is attributed to the chemical suppression effect of the potassium additive. This study concludes that the fire suppression effectiveness of fine water mists is not degraded with the addition of potassium acetate to lower the solution freezing point. On the contrary, the additive substantially increases the fire suppression effectiveness of the mist.

Acknowledgments

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